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Chapter 18: Web-based Tools—NED VO Services

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Introduction

The NASA/IPAC Extragalactic Database (NED) is a thematic, web-based research facility in widespread use by scientists, educators, space missions, and observatory operations for observation planning, data analysis, discovery, and publication of research about objects beyond our Milky Way galaxy. NED is a portal into a systematic fusion of data from hundreds of sky surveys and tens of thousands of research publications. The contents and services span the entire electromagnetic spectrum from gamma rays through radio frequencies, and are continuously updated to reflect the current literature and releases of large-scale sky survey catalogs. NED has been on the Internet since 1990, growing in content, automation and services with the evolution of information technology. NED is the world's largest database of cross-identified extragalactic objects. As of December 2006, the system contains approximately 10 million objects and 15 million multi-wavelength cross-IDs. Over 4 thousand catalogs and published lists covering the entire electromagnetic spectrum have had their objects cross-identified or associated, with fundamental data parameters federated for convenient queries and retrieval.

This chapter describes the interoperability of NED services with other components of the Virtual Observatory (VO). Section 1 is a brief overview of the primary NED web services. Section 2 provides a tutorial for using NED services currently available through the NVO Registry. The “name resolver” provides VO portals and related internet services with celestial coordinates for objects specified by catalog identifier (name); any alias can be queried because this service is based on the source cross-IDs established by NED. All major services have been updated to provide output in VOTable (XML) format that can be accessed directly from the NED web interface or using the NVO registry. These include access to images via SIAP, Cone-Search queries, and services providing fundamental, multi-wavelength extragalactic data such as positions, redshifts, photometry and spectral energy distributions (SEDs), and sizes (all with references and uncertainties when available). Section 3 summarizes the advantages of accessing the NED "name resolver" and other NED services via the web to replace the legacy “server mode” custom data structure previously available through a function library provided only in the C programming language. Section 4 illustrates visualization via VOPlot of an SED and the spatial distribution of sources from a NED *All-Sky* (*By Parameters*) query. Section 5 describes the new NED Spectral Archive, illustrating how VOTables are being used to standardize the data and metadata as well as the physical units of spectra made available by authors of journal articles and producers of major survey archives; quick-look spectral analysis through convenient interoperability with the SpecView (STScI) Java applet is also shown. Section 6 closes with a summary of the capabilities described herein, which greatly simplify interoperability of NED with other components of the

VO, enabling new opportunities for discovery, visualization, and analysis of multi-wavelength data.

1. NED Services

Objects in NED can be queried *By Name*, via any alias utilizing the NED name interpreter; *Near Name* or *Near Position* (cone search); via *IAU Format*; or *By Refcode* (Reference). *Advanced All-Sky (*a.k.a. *By Parameter*) queries utilize joint constraints on Redshift, Sky Area, Object Types, Survey Names, and Flux density/magnitude to construct galaxy samples. Images can be queried *By Object Name* or *By Region* on the sky. References can be queried by *Object Name* or by *Author Name*. The complexities of SQL are hidden from the user by the NED software and interface. Available data include Positions, Redshifts, Morphological and Spectral Classifications, Photometry and SEDs, Images, Spectra, Distances, Diameters, object Cross-IDs and statistical Associations, Reference Abstracts, and detailed Notes. Measurement uncertainties are included where available, and all information is cited and linked to the on-line literature via ADS.

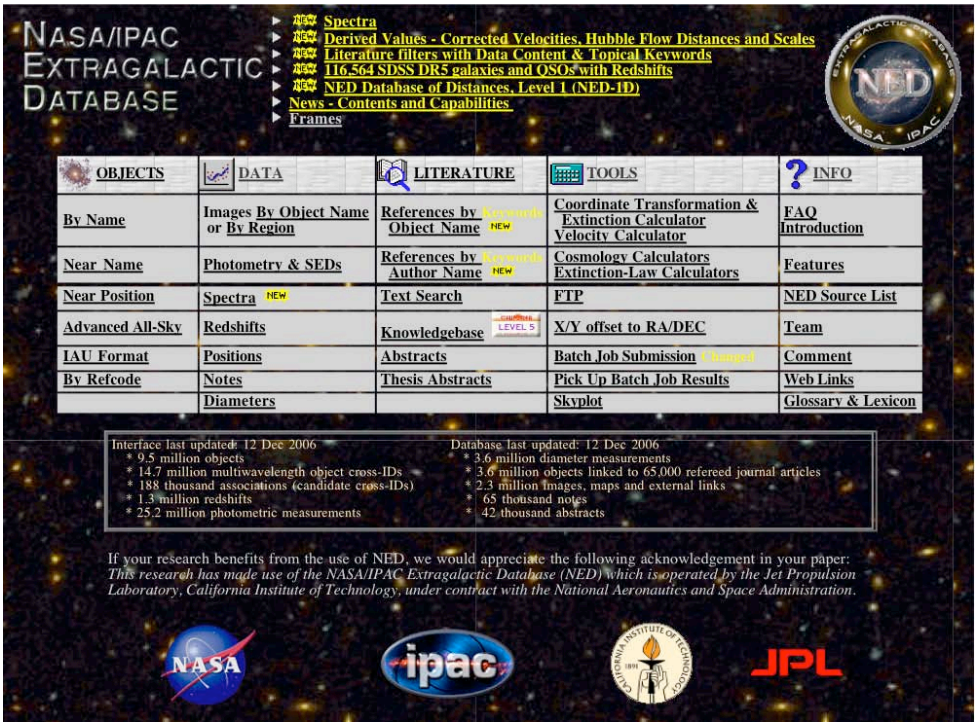

Figure 1. The NED main menu at `http://nedwww.ipac.caltech.edu/` (December 2006). Links into the primary VO-compatible web services discussed in this chapter are listed under the leftmost menu headings *OBJECTS* and *DATA*. Corresponding resources available through the NVO registry are summarized in Section 1.

Other tools include a *Coordinate Calculator* that performs conversions and precession and displays line-of-sight Galactic extinction estimates; a *Velocity Calculator* that converts among Heliocentric, Local Group, Galactic Standard of Rest, and 3K Microwave Background; an *XY-Offset to RA/Dec Converter;* and the *Level 5* Knowledgebase for Extragalactic Astronomy and Cosmology. Figure 1 illustrates NED's main interface menu, from which all of the above services are available. NED also has a batch mode that supports query forms submitted via email, and a "server mode" with a client C library used by remote data centers and observatory operations to resolve extragalactic object names into celestial coordinates and to perform object searches. For reasons explained below (Section 3), the C server mode is being superseded by VO-compatible web services.

2. NED VO Services

NED web services use the HTTP GET protocol whenever possible, with query filters and other options encoded as simple URL name/value pairs. This allows users to easily embed queries to NED in web pages, simplifies automated connections from nearly any modern programming or scripting language that can access web URLs, and enables access via simple utilities such as *curl* or *wget* for users with limited programming abilities.

In addition to HTML output modes, major NED services have recently been upgraded to offer an option for output in VOTable XML document trees, as well as simple ASCII tables. The services can be accessed directly at the NED web interface, or by using the NVO registry and harvesting methodologies (Greene et al. 2004). The VO-compatible services include queries to the NED image archive via Simple Image Access Protocol (SIAP), object searches using the Cone Search protocol, and numerous specialized services providing fundamental data and multi-wavelength relationships that can be filtered using various constraints. The meaning of the various query filters can be easily determined from the corresponding input form and help files on the NED server, or by using the *Reference URL* from the NVO registry search result.

Following is a summary of the key NED services available in the NVO Registry, grouped by Resource Type and including specific examples and pointers to documentation for usage.

2.1. Resource Type: CONE

Identifier	`ivo://ned.ipac/Basic_Data_Near_Position`
Short Name	NED(sources)
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?search_type=Near+Position+Search&of=xml_main&RA=Value&DEC=Value&SR=Value`

Notes: `RA` and `DEC` are in decimal degrees (J2000) and `SR` (search radius) is in degrees.

```
#Example: Query objects within 15 arcminute radius around M 83
http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?
search_type=Near+Position+Search&of=xml_main&
RA=204.253833&DEC=-29.865750&SR=0.25
```

2.2. Resource Type: Simple Image Access Protocol (SIAP)

Identifier	`ivo://ned.ipac/Image`
Short Name	NED(images)
Service URL	`http://irsa.ipac.caltech.edu/cgi-bin/Atlas/nph-nedsiap?mission=NED&hdr_location=%5CNEDDataPath%5C&SIAP_ACTIVE=1&collection_desc=NASA%2FIPAC+Extragalactic+Database+Image+Data+Atlas+%28NED%29&POS=Value,Value &SIZE=1.0`

Notes: `POS` contains RA,Dec (J2000) for the search position and `SIZE` is the search radius, all in decimal degrees.

```
#Example: Query images that overlap a 1.0 degree radius around POS
http://irsa.ipac.caltech.edu/cgi-bin/Atlas/nph-nedsiap?
mission=NED&hdr_location=%5CNEDDataPath%5C&SIAP_ACTIVE=1&
collection_desc=NASA%2FIPAC+Extragalactic+Database+Image+Data+Atlas
+%28NED%29&POS=13.56453,-13.789654&SIZE=1.0
```

2.3. Resource Type: TABULARSKYSERVICE

The following services query objects in various ways and return the results in VOTable XML format. The main search program, *nph-objsearch*, has a number of options that affect the results. The output format option, `of`, when set to value `xml_all` (XML, all) returns a VOTable containing nested tables ("table of tables"), each containing a specific type of source data. Specific data types are also available separately by specification of `of=xml_main` (main source table), `of=xml_names` (source cross-IDs), `of=xml_posn` (source position, with uncertainties when available), `of=xml_basic` (Basic Data), and `of=xml_extern` (links to External Resources at the source position). These options were provided by request of NVO client developers, to minimize the data transferred (via `xml_all`) when only specific information is desired.

The option `extend=no` requests data for only the object name specified by `objname; extend=yes` also returns data for objects associated to the queried `objname`, for example, H II regions within a galaxy or members of a galaxy group. The value provided for the parameter `objname` (object name) can be any alias recognized by the "name resolver" service, because the service is based on the extensive and continuously updated NED source cross-IDs.

1. Query basic data by specification of an object name

Identifier	`ivo://ned.ipac/Basic_Data_By_Object_Name`

Short Name	NED_by_objname
Documentation	`http://nedwww.ipac.caltech.edu/forms/byname.html`
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?extend=no&of=xml_all&objname=`**`Value`**

Note: With `of=xml_posn`, this is the web services version of the NED "name resolver," providing VO portals and related internet services with the best known celestial coordinates (smallest uncertainties when available) for an object specified by catalog identifier (objname). Other essential data for the object are also available, depending on the value of the output format (of) switch as described above.

```
# Example: Return all basic data for NGC 1068 (of=xml_all)
http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?
extend=no&of=xml_all&objname=NGC+1068

# Example: Return the best position, with uncertainties, for NGC 1068
http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?
extend=no&of=xml_posn&objname=NGC+1068
```

2. Query data for objects near a specified object name

Identifier	`ivo://ned.ipac/Basic_Data_By_Object_Name`
Short Name	NED_by_objname
Documentation	`http://nedwww.ipac.caltech.edu/forms/nearname.html`
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?search_type=Near+Name+Search&radius=`**`Value`**`&of=xml_main&objname=`**`Value`**

Note: This is similar to the service that supports the VO Cone protocol (Section 2.1), but it has the advantage of allowing input of a NED object name without knowledge of its coordinates (i.e. no need for an initial query to find the source coordinates).

```
# Example: Query objects within 2 arcminutes of Mrk 171
http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?
search_type=Near+Name+Search&radius=2.0&of=xml_main&objname=Mrk+171
```

3. Query objects based on IAU Name (truncated coordinates)

Identifier	`ivo://ned.ipac/Basic_Data_Near_IAU_Name`
Short Name	NED_near_IAUname
Documentation	`http://nedwww.ipac.caltech.edu/forms/iauformat.html`
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?search_type=IAU+Search&iau_name=`**`IAU_CoordinateBasedName`**`&radius=`**`Value`**`&of=xml_main`

```
# Example: Search within 7 arcminutes radius around 1234-123
http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?
```

```
search_type=IAU+Search&iau_name=1234-123&radius=7&of=xml_main
```

4. Query objects by journal reference (refcode)

Identifier	`ivo://ned.ipac/Basic_Data_By_Reference`
Short Name	NED_by_refcode
Documentation	`http://nedwww.ipac.caltech.edu/forms/byrefcode.html`
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?search_type=Search&refcode=`**`19DigitRefcode`**`&of=xml_main`

```
# Example: Query objects studied in 2003ApJS..147...29G
http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?
search_type=Search&refcode=2003ApJS..147...29G&of=xml_main
```

5. Retrieve source names (multi-wavelength cross-IDs) for an object

Identifier	`ivo://NED/Basic_Data_By_Object_Name`
Short Name	NED_names
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?extend=no&of=xml_names&objname=`**`Value`**

Note: Source names (aliases) in NED are not simply bibliographic; they are based on multi-wavelength catalog source cross-IDs established by the NED team.

```
# Example: Get cross-IDs with corresponding object types for NGC 1275
http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?
extend=no&of=xml_names&objname=NGC+1275
```

6. Retrieve the best position data for an object

Identifier	`ivo://NED/Basic_Position_Data_For_Object`
Short Name	NED_basic_posn
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?extend=no&of=xml_posn&objname=`**`Value`**

```
# Example: Get best position and uncertainties for 3C 273
http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?
extend=no&of=xml_posn&objname=3C+273
```

7. Retrieve basic data for an object

Identifier	`ivo://NED/Basic_Data_For_Object`
Short Name	NED_basic
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?extend=no&of=xml_basic&objname=`**`Value`**

```
# Example: Retrieve basic data for 3C 273
http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?
extend=no&of=xml_basic&objname=3C+273
```

8. Retrieve links to external data (at distributed data centers) for an object

Identifier	`ivo://NED/NED_External_Links_by_Object_name`
Short Name	NED_external
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?extend=no&of=xml_extern&objname=`**`Value`**

```
# Example: Retrieve links to external data at the position of 3C 273
http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?
extend=no&of=xml_extern&objname=NGC+4151
```

9. Retrieve all basic information for an object as a "table of tables"

Identifier	`ivo://NED/All_Basic_Data_For_Object`
Short Name	NED_all_basic
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?extend=no&of=xml_all&objname=`**`Value`**

Note: See the introduction of this section for an explanation of `of=xml_all`.

```
# Example: Retrieve all basic information for 3C 273
http://nedwww.ipac.caltech.edu/cgi-bin/nph-objsearch?
extend=no&of=xml_all&objname=3C+273
```

10. Query objects with joint constraints on Redshift, Sky Area, Object Types, Survey Names, and Flux density/magnitude to construct galaxy samples

Identifier	`ivo://ned.ipac/Basic_Data_AllSky_By_Param`
Short Name	NED_adv_all_sky_by_params
Documentation	`http://nedwww.ipac.caltech.edu/forms/byparams.html`
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-allsky?`

Notes: The service URL is followed by optional arguments given as Name-Value pairs. Utilize joint constraints on Redshift, Sky Area, Object Types, Survey Names, and Flux density/magnitude to construct galaxy samples. The complexities of SQL are hidden from the user by the NED software and interface.

```
# Example: Query objects with a redshift greater than 5.0
http://nedwww.ipac.caltech.edu/cgi-bin/nph-allsky?
z_constraint=Larger+Than&z_value1=5.0&z_value2=&z_unit=z&of=xml_main
```

The following queries return detailed, multi-wavelength data and metadata for a specified object.

11. Retrieve photometric data and a SED for a specified object name

Identifier	`ivo://ned.ipac/Photometric_Data`
Short Name	NED_photo_data
Documentation	`http://nedwww.ipac.caltech.edu/forms/nearname.html`
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-datasearch?search_type=Photometry&of=xml_main&objname=`**`Value`**

```
# Example: Retrieve photometry as an SED tabulation for NGC 1275
http://nedwww.ipac.caltech.edu/cgi-bin/nph-datasearch?
search_type=Photometry&of=xml_main&objname=NGC+1275
```

12. Retrieve multi-wavelength diameter (size) information for a specified object name

Identifier	`ivo://ned.ipac/Diameters_By_Object_Name`
Short Name	NED_diameters
Documentation	`http://nedwww.ipac.caltech.edu/forms/diam.html`
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-datasearch?search_type=Diameters&of=xml_main&objname=`**`Value`**

```
# Example: Retrieve multi-wavelength diameter data for NGC 1275
http://nedwww.ipac.caltech.edu/cgi-bin/nph-datasearch?
search_type=Diameters&of=xml_main&objname=NGC+1275
```

13. Retrieve multi-wavelength redshift information for a specified object name

Identifier	`ivo://ned.ipac/Redshifts_By_Object_Name`
Short Name	NED_photo_data
Documentation	`http://nedwww.ipac.caltech.edu/forms/z.html`
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-datasearch?search_type=Redshifts&of=xml_main&objname=`**`Value`**

```
# Example: Retrieve multi-wavelength redshift data for NGC 1275
http://nedwww.ipac.caltech.edu/cgi-bin/nph-datasearch?
search_type=Redshifts&of=xml_main&objname=NGC+1275
```

14. Retrieve references for a specified object name

Identifier	`ivo://ned.ipac/References_Data_by_Object_Name`
Short Name	NED_search_ref
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-datasearch?search_type=Reference&of=xml_main&objname=`**`Value`**

```
# Example: Retrieve references for NGC 1275
```

```
http://nedwww.ipac.caltech.edu/cgi-bin/nph-datasearch?
search_type=Reference&of=xml_main&objname=NGC+1275
```

15. Retrieve detailed notes for a specified object name

Identifier	`ivo://ned.ipac/Notes_By_Object_Name`
Short Name	NED_search_notes
Documentation	`http://nedwww.ipac.caltech.edu/forms/notes.html`
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-datasearch?search_type=Notes&of=xml_main&objname=`**`Value`**

```
# Example: Retrieve notes for Arp 220
http://nedwww.ipac.caltech.edu/cgi-bin/nph-datasearch?
search_type=Notes&of=xml_main&objname=Arp+220
```

16. Retrieve multi-wavelength position data for a specified object name

Identifier	`ivo://ned.ipac/Positions_By_Object_Name`
Short Name	NED_search_pos
Documentation	`http://nedwww.ipac.caltech.edu/forms/position.html`
Service URL	`http://nedwww.ipac.caltech.edu/cgi-bin/nph-datasearch?search_type=Position&of=xml_main&objname=`**`Value`**

```
# Example: Retrieve multi-wavelength positions for M 83
http://nedwww.ipac.caltech.edu/cgi-bin/nph-datasearch?
search_type=Positions&of=xml_main&objname=M+83
```

3. New Ways for Remote Client Applications to Interface with NED

Numerous Internet services, observation tools, and computer programs developed by astronomers around the world use the legacy NED "server mode" for direct connectivity to NED. The NED server mode has been supported for over a decade. However, we encourage people developing new client applications, or maintaining old ones, to utilize the new NED VO web services for the following reasons: (1) The legacy client-server mode for access to NED is quite limited in the queries supported and in the supplied data, whereas connectivity via web VO services provides access to nearly all NED services and content types. (2) The C client-server interface was developed as a separate code branch that is no longer being enhanced; it is much more efficient to support automated access from client programs and interactive access by people via web browser using the same code base. (3) Some sites have reported problems accessing NED's server mode on port 10011 due to local firewall restrictions; the NED public web services are provided at the standard HTTP server port 80. (4) The legacy NED client package was available only in the C language, whereas the web services can be used like functions or method calls from any computer language that can access HTTP URLs. (5) The client-server mode utilized a

custom data structure; any XML/VOTable parser can be deployed by the programmer to read the NED query results from the web services.

Section 2 provided examples of utilizing the web services to query NED for the classic "name resolver" function and searching for objects and data in various ways. There are a number of recent developments in this area. The Spitzer Planning Observations Tool (SPOT, and its derivatives iSPOT and HSPOT) developed at the Spitzer Science Center and IPAC are being upgraded to utilize the NED web VO services. The NVO data discovery and browsing tool DataScope (`http://heasarc.gsfc.nasa.gov/vo/`) connects to a number of NED VO services (via the Registry). Source name to coordinate look-up ("name resolution") is a key component under the hood of the main NVO web site (`http://www.us-vo.org`) and in other emerging VO tools that are successfully using NED's modern web services rather than the legacy C server.

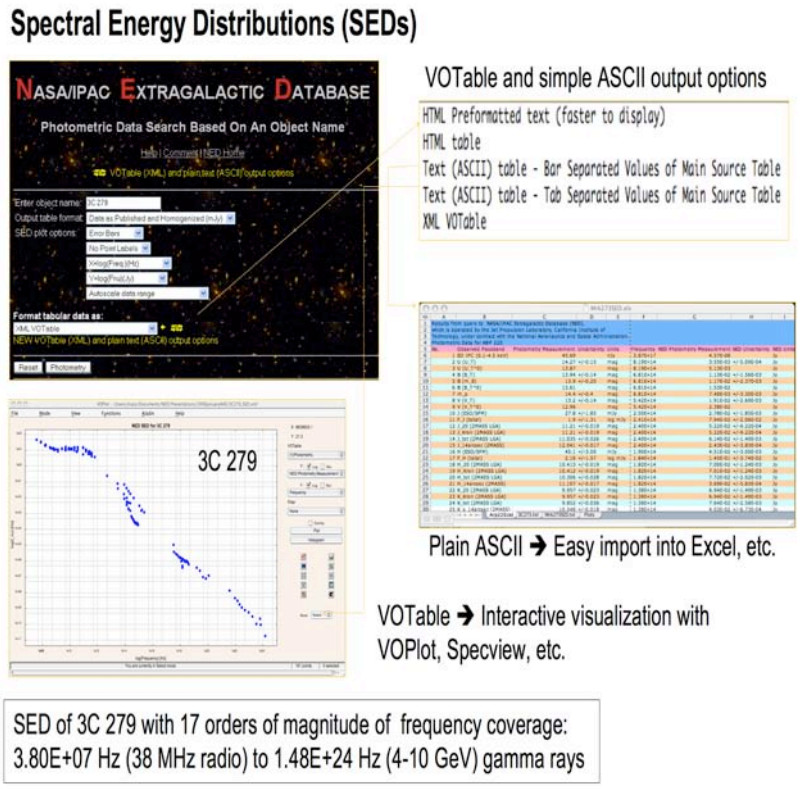

Figure 2. The SED for 3C 279 extracted from NED in VOTable format and plotted with VOPlot (left) and extracted in simple tab-delimited ASCII for import into Excel (right).

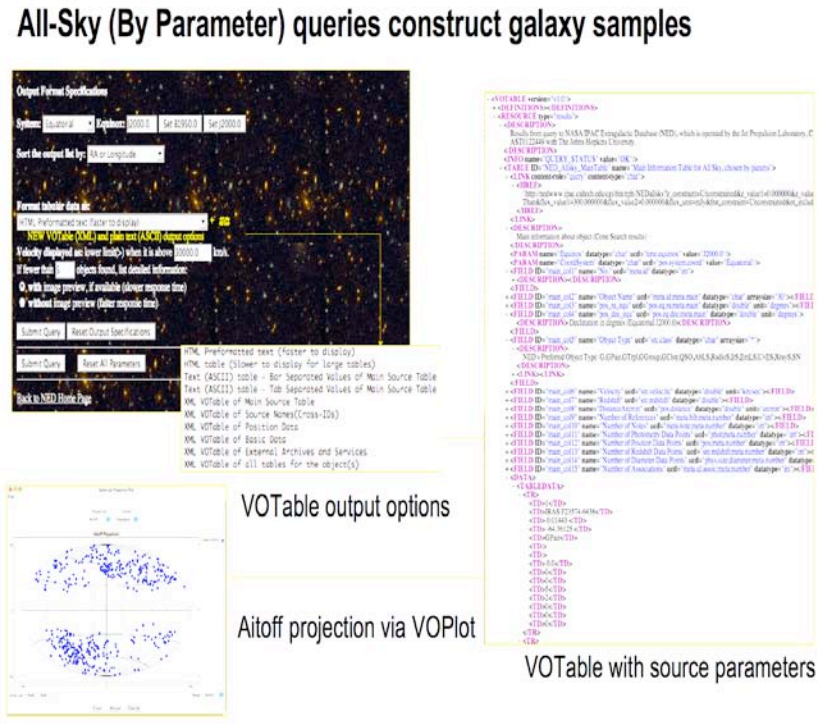

Figure 3. The results of a NED *All-Sky* (*By Parameters*) query, plotting the sky distribution of a galaxy sample using VOPlot.

4. Example NED VO Data FlowsExample NED VO Data Flows

4.1. Query a SED from NED and Import into VOTable or Excel

Following the example above (Section 2.3.11), we can retrieve data and metadata for NED's extensive SED for 3C 279 using wget as follows:

```
wget -O NED_3C279_SED.xml "http://nedwww.ipac.caltech.edu/cgi-
bin/nph-datasearch?search_type=Photometry&objname=3C+279&of=xml_main"
```

Then the VOPlot Java application can be used to visualize the data stored in the local data file NED_3C279_SED.xml. By changing the output format parameter to request tab-separated ASCII table (`of=ascii_tab`), we can easily import the data file into Excel (or OpenOffice) or other applications for analysis. See Figure 2.

4.2. Plot the Spatial Distribution of a NED Galaxy Sample Using VOPlot

Use wget to query NED for objects with a redshift greater than 4, storing the results in a VOTable, followed by import into VOPlot to view the spatial distribution:

```
wget -O NEDallsky_Zgt4.xml
"http://nedwww.ipac.caltech.edu/cgi-bin/nph-allsky?
z_constraint=Larger+Than&z_value1=4.0&z_value2=&z_unit=z&of=xml_main"
```

At the time of writing (Dec 2006), the result from this query returns in 35 seconds and contains data for 3896 objects. Figure 3 illustrates a similar query.

5. VO Compatibility in the New NED Spectral Database

In December 2006, NED released the initial version of a new Spectral Database for extragalactic sources. The service is patterned after the success of NED's image archive and provides the following primary features: (1) a unique repository for spectra previously published only via rendered plots in journal articles; (2) value-added access to spectra from large survey archives; (3) linkage of spectra to other data in NED; (4) preview plots of the spectra and instrument apertures superposed on galaxy images; (5) preservation of the original data format provided by authors and archive curators; (6) standardized (MKS) units using a uniform VO-compatible data format; (7) ASCII and VOTable download options; (8) a query service to locate spectra by object name, journal article (refcode), passband, line filters, and combinations thereof; (9) quick-look visualization and analysis; (10) interoperability with the VO/

VOTable is used to standardize the data structure and physical units of spectra provided in various FITS and ASCII formats. The VOTable format is also used to facilitate comparison, fusion, and analysis of spectra via VO-compatible Java applets such as Specview (Busko 2000) and VOPlot (Kale et al. 2004). Figure 4 illustrates the initial VO capabilities of the NED spectral archive. The addition of significantly more spectral data is in progress. Plans for future upgrades, as resources permit, include a VOTable output mode for the spectrum search results, queries via Simple Spectral Access protocol, and additional metadata in a common VO data model (UNAMEs, UCDs, etc.).

6. Summary

In this era of escalating growth in data volume and complexity, NED is continuing its evolution as a major astronomical research facility in its own right, and as a key VO service provider and portal. The NED VO services and work flows described here, utilized in concert with other components of the emerging VO described elsewhere in this volume, empower astronomers everywhere with extensive tools to automate queries and analyze and visualize multi-wavelength data in ways we could only dream of a few years ago. Space limitations permitted illustration of only a small subset of the NED services. Additional information about NED activities and services in context of the VO, including extensive linkage between NED and data centers distributed around the world, is available in a recent review presented at ADASS XVI (Mazzarella 2006). A more graphics-rich overview of the latest NED content and capabilities

may be viewed in the handout from the January 2007 meeting of the AAS (`http://nedwww.ipac.caltech.edu/docs/NED2007/JanHand-out.pdf`).

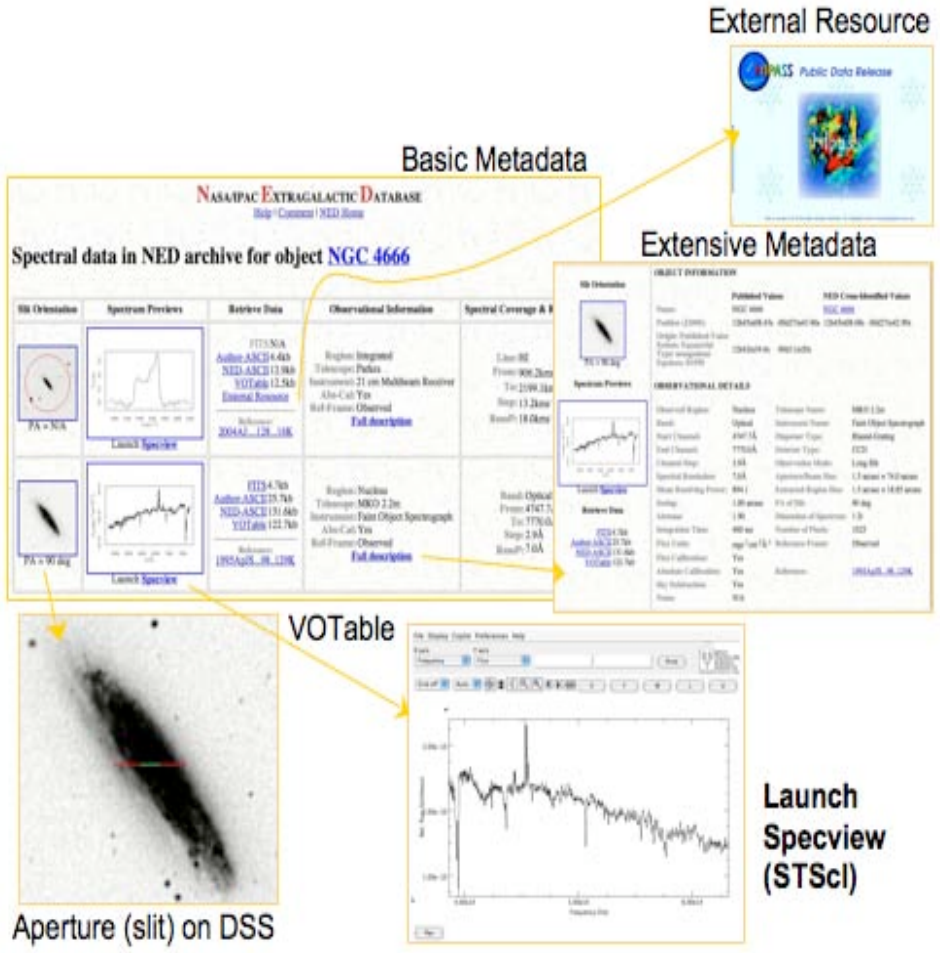

Figure 4. The NED spectral database. VOTables are created and served to standardize the data and metadata format as well as the physical units of spectra made available by authors of journal articles and producers of major survey archives.

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ing Group. NED-1D flourishes due to the dedication and enthusiasm of Ian Steer. The new spectral database was developed by Ben Chan. Special thanks go to the IPAC System Group and Eugene Hacopians of the Spitzer Science Center for excellent work in upgrading and maintaining the NED computing infrastructure.

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Useful Links

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